NOLTR 61-29

N-62-3-6

METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS

23 JUNE 1961

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS

Prepared by:

A. E. Seigel

ABSTRACT: The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.

PUBLISHED JANUARY 1962

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 61-29 23 June 1961

This report represents an outline of a method of calculating the performance of high-speed light-gas guns. This is one of a series of basic interior ballistics reports written at the U. S. Naval Ordnance Laboratory during the past eight years in which time the speeds achieved by laboratory guns have increased from 13,000 to 31,000 feet per second.

W. D. COLEMAN
Captain, USN
Commander

R. KENNETH LOBB
By direction

CONTENTS

	Page
Introduction	1
The Behavior of the Projectile Propelled by the Expanding Propellant Gas	3
The Influence on the Projectile Behavior as a Result of the Gas in the Front of the Projectile in the Barrel	8
Calculation of the Effect of Friction and Heat Transfer on the Motion of the Projectile	10
Calculation of a Two-Stage Gun	11
Appendix	17
References	18

ILLUSTRATIONS

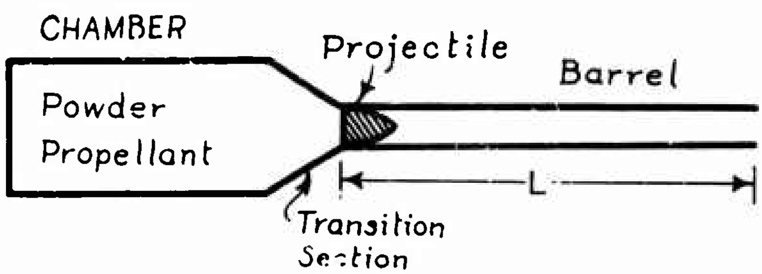
		Page
Figure 1	Projectile Velocity - Initial Sound Speed for all γ_o's(D_o/D_1 = 1_o, $X_o = \infty$)	19
Figure 2	Performance Curve for Pre-Burned Propellant Gun with D_o/D_1 1, $X_o = \infty$	20
Figure 3	Projectile Velocity Travel Plot for Pre-Burned Propellant Gun (D_o/D_1 = 2, γ = 1,4).	21
Figure 4	Approximate Projectile Velocity for Case when Gas is Present in Barrel in Front of Projectile	22
Figure 5	Tentative Projectile Velocity Plot to be used to Account for Viscous Effects . . .	23
Figure 6	Sequence of Events Occurring in Two-Stage Gun	24
Figure 7	Two-Stage Gun Time-Distance Plot	25
Figure 8	Pressure Behind Piston Given as a Function of Position	26
Figure 9	Projectile Velocity in Two-Stage Launcher vs. Travel Distance in Calibers	27
Figure 10	Typical Experimental Pressure Trace in Front Chamber.	28

METHODS OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS

INTRODUCTION

Up until 1945, after 700 years of shooting guns, the maximum velocity of projectiles was 10,000 feet per second. However, during the past thirteen years the projectile velocities obtainable from laboratory guns have risen from 10,000 feet per second to 30,000 feet per second. This increase in velocity during a relatively short period of time was the result of a vigorous effort pursued to make possible the study of hypervelocity phenomena in the laboratory. During the course of this effort our knowledge of the interior ballistics process increased and is continuing to increase.

Schematically, a conventional powder propellant gun may be represented as sketched below.



The chamber contains the propellant. It is joined by means of a transition section to a smaller diameter barrel of cross-sectional area, A. The projectile mass is denoted by M and the length of the barrel is denoted by L. When the propellant is ignited, it begins to burn forming a gas. This gas pushes on the projectile, propelling it along the barrel.

To obtain an expression for the velocity of the projectile as it leaves the barrel, it is noted that the work which has

been done on the projectile by the propellant gas is equal to the kinetic energy acquired by the projectile.* Thus,

$$MV^2/2 = \int_0^L Ap\,dy \tag{1}$$

With $\bar{p}$, the spatial average pressure defined as

$$\bar{p} = \int_0^L p\,dy / L \tag{2}$$

the projectile velocity becomes

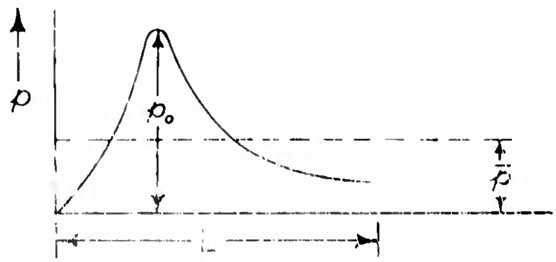
$$V = \sqrt{2\bar{p}AL/M} \tag{3}$$

This result, equation (3), indicates essentially the factors upon which the projectile velocity depends. To increase the projectile velocity, one must increase the value of the quantity under the square root sign. Thus, one method of achieving a higher projectile velocity might be to change the sizes of the projectile and barrel so as to increase the value of AL/M; this requires for a given barrel cross-sectional area, A, that M be made smaller and L larger. (Note that if a gun is made larger by scaling it, AL/M remains the same.) However, practicality limits these changes, for M may be made only so small for a given barrel diameter and L may be made only so large (as frictional effects lower $\bar{p}$ substantially if the barrel is too long -- see below). Unfortunately, after having made AL/M as large as practical, it is found with a conventional propellant that the projectile velocity is still much below that desired.

From the above situation one is led to the conclusion that since AL/M is limited the only method of achieving high velocity is to increase the average pressure, $\bar{p}$.

The reason for the difficulty in obtaining a high average pressure in the case of the conventional gun is illustrated by the sketch on the following page.

*The air pressure in front of the projectile has been assumed negligible here, as has been the frictional force acting on the projectile.



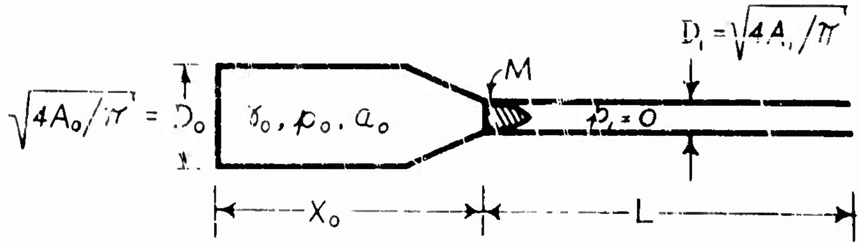
Here the pressure behind the projectile in the conventional gun is plotted as a function of its travel. The rise in pressure from zero to the peak pressure, p_o, results from the burning of the propellant; the rapid pressure decrease is a result of the propellant inertia. It is evident that the average pressure, $\bar{p}$, is considerably below the peak pressure, p_o, for the conventional propellant. Increasing the amount of propellant in the chamber would increase p_o and thus $\bar{p}$, but the strength of the gun limits the value of p_o.

(Since increasing AL/M is difficult, as is increasing $\bar{p}$, the question occurs, why don't we change the 2 in the expression square root of $2\bar{p}AL/M$ to a 3, or a 7?)

It seems logical to assume that one method of increasing the average pressure is to restrain the projectile from movement until the reacting propellant pressure reaches the peak pressure. In this way the initial pressure that the projectile feels when it first moves is the high value of the peak pressure. The problem then becomes one of maintaining this high pressure as the projectile moves along the barrel. This is the main problem of interior ballistics, the solution of which makes possible the attainment of high velocity.

THE BEHAVIOR OF THE PROJECTILE PROPELLED BY THE EXPANDING PROPELLANT GAS

Let the gun system to be considered be one in which the propellant has been completely burned before the projectile is allowed to move (a pre-burned propellant gun). At the moment of projectile release, it is visualized as sketched on the following page.



When the chamber diameter is greater than the barrel diameter ($D_0/D_1 > 1$), the gun is described as a "chambered" gun, or a gun with "chambrage." For convenience, the propellant gas is assumed to be an ideal gas. It may be demonstrated in such a gun (see reference (1)) that when the projectile moves along the barrel, the pressure drop behind may be thought of as being controlled by two factors: firstly, and most important for high-speed guns, the gas inertia (which determines how quickly the gas can rush into the vacated region left by the projectile), and, secondly, the chamber geometry (which determines how much gas is available to push).

It has been found that in the unsteady expansion process occurring in such a gun, the gas inertia pressure drop may be decreased by employing a propellant gas with a large initial sound speed, a_0 , and small specific heat ratio, γ_0.* Since the specific heat ratios of gases do not differ appreciably, the search has been for propellant gases with high sound speeds. For an ideal gas, the sound speed is proportional to the square root of the temperature divided by the molecular weight. Thus, one is led to use as a propellant gas a low molecular weight gas, such as hydrogen or helium, at elevated temperatures.

For a given chamber diameter, increasing the chamber length, X_0, will make the pressure drop behind the projectile smaller, and thus the projectile velocity larger, until the chamber length becomes sufficiently long that it no longer influences the projectile behavior; this length chamber is

*The requirements for a non-ideal propellant gas are discussed in reference (2).

known as an "effectively infinite length chamber."* Making a chamber longer than this length does not increase the velocity of the projectile.

For a given chamber length, increasing the chamber diameter will increase the projectile velocity. However, for effectively infinite length chambers, increasing the diameter ratio D_0/D_1 beyond 3 yields very little projectile velocity increase, as is shown in reference (3) and discussed below.

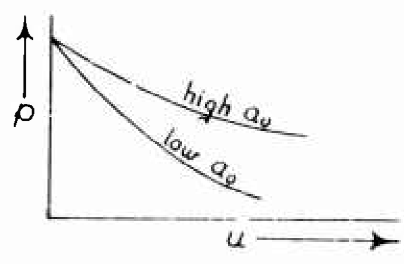
The above statements concerning the behavior of a pre-burned propellant gun may be presented quantitatively by assuming that (1) the propellant gas expands isentropically (that is, without significant viscous and heat-transfer effects), (2) the gas is an ideal gas, and (3) the gas pressure in front of the projectile is negligible. Thus, Newton's law applied to the projectile is

$$M\,du/dt = Mu\,du/dy = pA, \tag{4}$$

For a gun with an effectively infinite length chamber with the same diameter as the barrel ($D_0/D_1 = 1$), the pressure behind the projectile may be expressed as a function of the projectile velocity (see, for example, references (3) and (5)).

$$p = p_0\left[1 - \frac{u}{\frac{2}{\gamma_0 - 1}\,a_0}\right]^{2\gamma_0/(\gamma_0-1)} \tag{5}$$

It is noted from this equation that a high initial sound speed, a_0, minimizes the pressure drop behind the projectile.

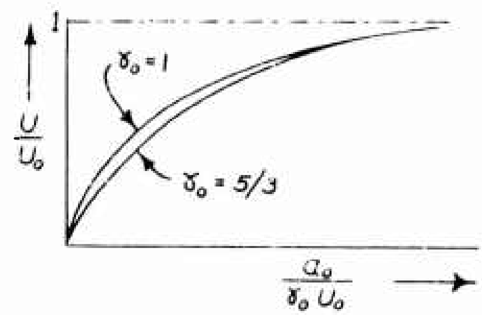


*An effectively infinite length chamber is one sufficiently long so that the disturbances originating from the projectile and subsequently reflecting from the chamber back end do not reach the projectile (see reference (3)).

Inserting equation (5) into Newton's equation (4) yeilds an analytic expression for the distance traveled by the projectile as a function of the projectile velocity (references (1), (3), or (4)).

$$\frac{p_0 A_1 X}{M a_0^2} = \frac{2}{\gamma_0 + 1}\left[\frac{2 - (\gamma_0 + 1)\left(1 - \frac{u(\gamma_0 - 1)}{2a_0}\right)}{(\gamma_0 - 1)\left(1 - \frac{u(\gamma_0 - 1)}{2a_0}\right)^{(\gamma_0+1)/(\gamma_0-1)}} + 1\right]$$

A most useful presentation of this relation is shown in Figure 1 which is a plot of dimensionless projectile velocity, U/U_0, versus dimensionless initial sound speed $a_0/\gamma_0 U_0$. U_0 is the $\sqrt{2p_0 A_1 X/M}$, the projectile velocity attainable if the projectile is propelled by a constant pressure, p_0. This plot is nearly a single curve for all γ_0 values.

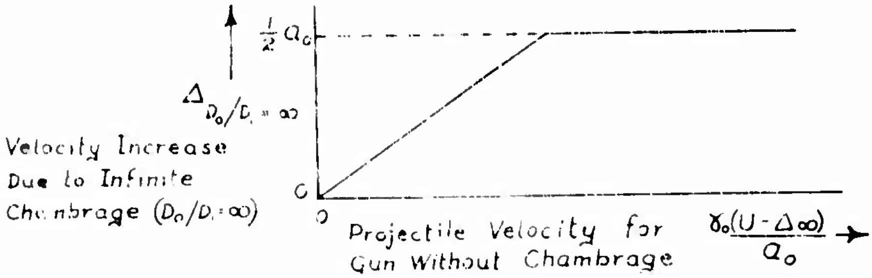


The ordinate may be thought of as an efficiency in maintaining the initial peak pressure. It is seen that this efficiency is high for high dimensionless sound speed and low for low dimensionless sound speed.

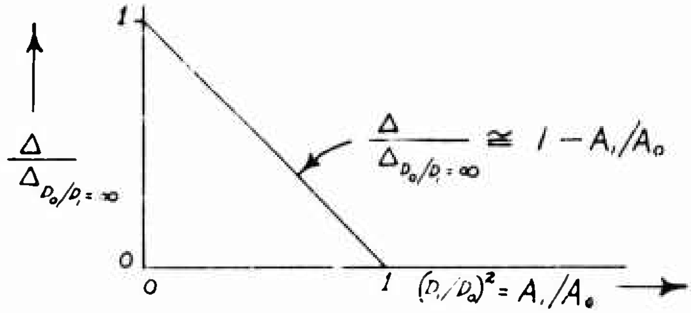
For an effectively infinite length chamber of diameter greater than the barrel diameter ($D_0/D_1 > 1$), the projectile behavior must be obtained by a numerical method, such as the method of characteristics (see references (1) and (3)).* The results of such calculations indicate that for a gun with infinite diameter ratio, the velocity increase, Δ, over a gun with no chambrage is at the lower speeds proportional to the

*For this calculation one-dimensional unsteady flow is assumed in the chamber and in the barrel, while quasi-steady flow is assumed in the transition section.

projectile speed. At high projectile speeds, Δ is equal to one half the initial sound speed of the propellant gas (see reference (2)). Thus, Δ due to infinite chambrage is approximated as shown in the plot below.



Further, it may be shown (reference (2)) that for finite diameter ratios, Δ is a function of D_o/D_1, as sketched below.

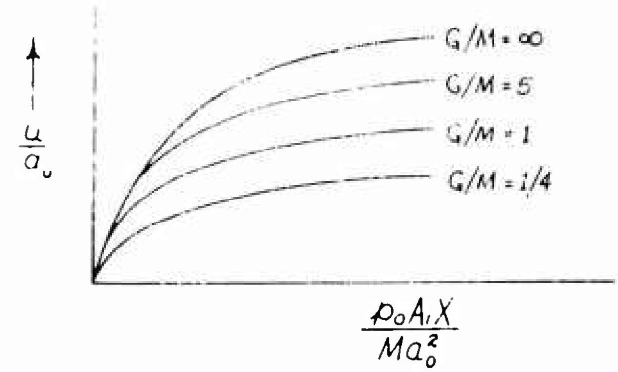


Thus, Δ , the increase of velocity due to chambrage, is a function of area ratio and projectile velocity as shown quantitatively in the lower right of Figure 2. To calculate the velocity of an effectively infinite length chambered gun, one need only calculate the velocity of a gun without chambrage, and then add to this velocity the value of Δ as obtained from the lower right of Figure 2. Hence, any performance curve for a gun with no chambrage becomes one for a gun with chambrage if for U is substituted $U - \Delta$.

In this manner the plot of Figure 1 has been replotted in Figure 2 to apply to the case of a chambered gun for effectively infinite length chamber.

The behavior of the projectile in the general case for a chambered gun whose length of chamber is less than the effectively infinite length must be calculated by numerical methods. The results of such calculations may be expressed in the form

of dimensionless plots similar to those of Figures 2 or 1, or they may be in terms of other dimensionless variables. Thus, a plot of dimensionless projectile velocity versus dimensionless projectile travel for a given geometry (i.e., for a given D_0/D_1 and given dimensionless X_0's) has been found convenient. Such a plot of a γ_0 = 1.4 propellant gas and a D_0/D_1 equal to 2 is shown in Figure 3 and sketched below.



In this plot the dimensionless X_0 is expressed as G/M, where G is the propellant gas mass, and M is the projecti.e mass. Thus,

$$G/M = \rho_0 A_0 X_0/M = \gamma_0 p_0 A_0 X_0 / a_0^2 M$$

Curves such as shown in Figure 3 for all diameter ratios, all chamber lengths, and all γ_0's are presently being calculated by the use of electronic computing machines. For the effectively infinite chamber length case the plots of Figures 1 and 2 will suffice.

THE INFLUENCE ON THE PROJECTILE BEHAVIOR AS A RESULT OF THE GAS IN FRONT OF THE PROJECTILE IN THE BARREL

If there is gas in front of the projectile, the forward motion of the projectile will be resisted by this gas. Shortly after the projectile begins to move, a shock will form in front of the projectile in a position in the barrel which depends on the initial acceleration and the initial sound speed of the gas in front (see references (5) and (6)). As the projectile increases in velocity the shock will increase in strength, and the pressure in front of the projectile will increase. The equation of motion for the projectile in this case becomes

$$du/dt = u\,du/dx = (p_b - p_f)A_1/M \tag{6}$$

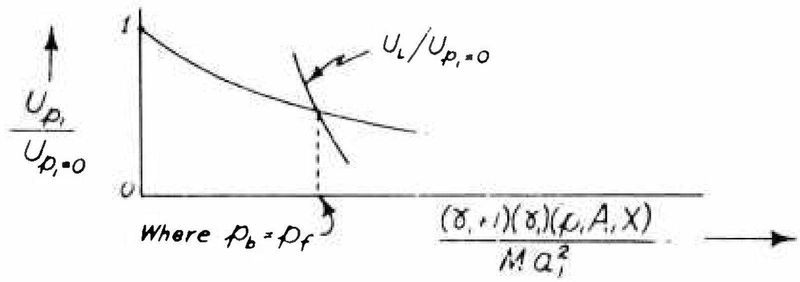
where p_b is the propellant pressure in the back and p_f is the pressure in the front of the projectile. The exact calculation of the behavior of the projectile may be done using the method of characteristics for the gas in the back, and using the method of characteristics and the shock equations for the gas in front. However, the calculations are quite lengthy.

The approximate behavior of the projectile may be found, however, without resorting to numerical integration in each particular case by employing the equation (7) below. This equation gives the ratio of projectile velocity with gas in front, U_{p_1}, to the velocity without gas in front, $U_{p_1=0}$.

$$\frac{U_{p_1}}{U_{p_1=0}} = \sqrt{\left(1 - \frac{p_1}{p_0}\right)\left(\frac{1-e^{-y}}{y}\right)} \tag{7}$$

where $$y \equiv \frac{(\gamma_1+1)(\gamma_1)(p_1 A_1 X)}{M a_1^2}$$

This equation, which is applicable to an effectively infinite length chambered gun,* is plotted in Figure 4. It is applicable until the pressure in the front becomes equal to the pressure in the back (as will be the case for large values of the abscissa). At that time $p_b = p_f$ and the velocity of the projectile denoted by U_L no longer increases. The method of obtaining U_L is outlined in the appendix. In this circumstance the dimensionless distance traveled by the projectile will be obtained by calculating $U_L/U_{p_1=0}$ and superimposing this plot on Figure 4 as shown below.



*This equation was derived on the basis of a constant pressure driving the projectile. Nevertheless, it agrees very well with exact solutions obtained numerically.

The use of this figure to obtain the effect of the gas pressure in the barrel on the projectile behavior has been compared to the results of the numerical integration and has been found to agree very well.

CALCULATION OF THE EFFECT OF FRICTION AND HEAT TRANSFER ON THE MOTION OF THE PROJECTILE

In recent years much theoretical and experimental work has been done on the study of the propulsion of a projectile inside a gun tube by means of an expanding propelling gas. A careful study previously done, reference (7), has shown that the assumption that the propelling gas expands reversibly (without gas viscous effects and gas heat-transfer effects) is justified for a low velocity (that is, velocities below 3,000 feet per second). In this previous study the motion of a piston propelled in a constant diameter tube was measured. The propelling gas was nitrogen initially at room temperature and pressures between 300 and 3,000 atmospheres. A comparison between the experimentally measured motion and the theoretically predicted motion showed the propelling gas could be considered to be expanding isentropically.

Recent results, however, with guns using high temperature light gases, firing projectiles at velocities between 12,000 and 30,000 feet per second, indicate a discrepancy between the experimental results and the isentropic theory. This discrepancy, which increases with increasing projectile velocity, is thought to be a result of the friction and heat transfer between the gas and the walls which exist during the gas expansion process. Calculation of gas friction and gas heat-transfer effects has not been carefully done for the case of the high velocity guns. These effects are accounted for in the calculation of conventional powder gun performance by an approximate method which assumes (see, for example, reference (6)), (a) that the steady flow results for heat transfer and friction apply to this basically unsteady process, (b) a linear gas velocity distribution in lieu of a velocity distribution obtained by a rigorous gas dynamics analysis, and (c) that the effects of friction and heat transfer on velocity are small relative to the inertia effects. The above method, when applied to high velocity gas guns, has been found to yield obviously incorrect results; this is believed to be due to the incorrectness of assumptions (b) and (c). It is therefore thought that a more careful analysis without these assumptions should be applied in the calculation of the performance of a high-speed gas gun, and then this analysis should be experimentally checked. This procedure is now being attempted at the U. S. Naval Ordnance Laboratory with the use of a high-speed

light-gas gun to obtain experimental results, and an electronic computing machine for the calculations.

A qualitative analysis of the effect of gas friction and heat transfer on gun performance may be made, for example, by dimensionless analysis. From such an analysis it may be concluded that the ratio of projectile velocity with friction, U_F, to that without friction, $U_F = o$, is mainly a function of

$$\frac{U_F}{U_{F=0}} = \phi\left(\frac{u}{a_0}, \frac{L}{D_1}, \gamma_0\right)$$

with other dimensionless parameters such as Reynolds number, Mach number, etc., being considered not essentially important. Then, since γ_0 does not vary too widely, this ratio would be a function of u/a_0 alone for guns of approximately the same L/D_1.

Based on experimental results with high velocity guns at the U. S. Naval Ordnance Laboratory, a curve of $U_F/U_F = o$ has been drawn versus u/a_0 and is shown in Figure 5. Tentatively, it is proposed that this plot be employed to take account of the friction and heat-transfer effects until the more careful study referred to above be completed. It is to be noted in Figure 5 that below u/a_0 of 1-1/2 the friction effects appear to be not important. Above this value of u/a_0 these effects become of greater and greater importance. The plot of Figure 5 demonstrates that a high sound speed causes the friction effects to be small relative to the inertia effects in a high-speed gun.

CALCULATION OF A TWO-STAGE GUN

In order to obtain a higher sound speed propellant gas than is possible as a result of a chemical reaction, energy may be added in other ways to the propellant gas. For example, an electrical discharge may provide the energy. A more convenient method is the principle used in the so-called "two-stage" gun where energy is provided by compressing the propellant gas which may be initially unheated or heated. Such a two-stage gun is sketched in Figure 6.

Initially the pressure p_0 of the back chamber gas is high relative to the pressure p_1 of the front chamber gas. In operation the high pressure gas in the back chamber ruptures the diaphragm "A" and then pushes the piston of mass, M, into the gas in the front chamber, heating it and compressing it.* When

*The performance of the case where the piston mass, M, equals zero is discussed in reference (8).

the pressure in the front chamber reaches a sufficiently high value, the diaphragm "B" separating the front chamber from the barrel ruptures and the projectile is propelled along the barrel by the gas in the front chamber.

It is possible by this method to obtain much higher sound speeds in the compressed gas in the front chamber than could be achieved in the propellant gas in a single chamber by heating it chemically. Thus, the gas in the front chamber reaches a higher value of sound speed than the value of sound speed, a_o, in the back chamber. Of course, all the energy imparted to the gas in the front chamber comes from the gas in the back chamber; the piston provides an efficient means to transfer this energy; its inertia makes it possible to compress the gas in front to very high internal energies at the expense of the internal energy of the gas in the back.

To calculate the events which occur in such a gun, it is recommended that an electronic computing machine be used (but, then one would tend not to gain a basic understanding of the process, and this report would be unnecessary). However, the methods given above may be advantageously applied to calculate approximately the projectile motion.* Easily calculated by these methods are the conditions that exist when the shock in front of the piston has reflected from the front of the front chamber and has reached the piston, i.e., the conditions shown in Diagram C, Figure 6.** At this time the velocity of the gas in front (in state 3) is zero, and therefore this gas has no kinetic energy. The procedure, then, is to apply the first law to the system consisting of the piston and the gas in front of the piston; the first law is applied between the state existing in Diagram C and any subsequent state of the system. The assumptions which are made are:

(1) The gas in front changes state reversibly after the state shown in Diagram C (see footnote ** below).

(2) The kinetic energy of the gas at any time after the state in Diagram C is equal to $1/2\ G/3V^2$.

(3) The pressure behind the piston, p_b, is that experienced by a piston which is suddenly moved at velocity $V_3 - V$ into a gas at state 3.

*One should note reference (10) where another approximate analysis is presented for a two-stage gun system.
**In some cases it may be desirable to calculate the conditions at a time when the shock has gone forth and back a second time.

Assumption (1) is a valid one because the irreversibility associated with the second and third reflections is small, as may be calculated by the methods of reference (9). Assumption (2) is deduced from the assumption of a linear velocity distribution. Assumption (3) agrees well with numerical calculations (and the magnitude of the term containing p_b is small in most cases (see Figure 8). If the projectile is released before the piston is brought to rest, the amount of gas going into the barrel may be determined by assuming a sonic exit velocity. The projectile velocity is then obtained by use of Figures 2, 4, and 5 at points along the barrel with the use of the corresponding reservoir conditions (which are changing with time). If the initial loading pressure in the front chamber, p_1 is sufficiently low, the calculation indicates that the piston will be still moving forward when it reaches the front of the front chamber. If this be the case, clearly the piston should be designed so as actually to enter the barrel to provide still further "push" to the projectile. This idea is the basis of the new high velocity gun currently being used at the NASA, Ames Research Center (reference (11)).

The above procedure in itself is a tedious one. It has been found that a good approximation is to assume that the projectile is released at the time the piston comes to rest; that is, the time shown in Diagram D in Figure 6. Thereafter, the projectile motion is determined by the conditions of the reservoir at state S, as shown in Diagram D of Figure 6. For this situation the first law equation yields

$$\frac{T_s}{T_3} = 1 + \frac{M}{2G}(\gamma_1 - 1)(\gamma_1)\left(\frac{V}{a_3}\right)^2 + \frac{\gamma_1 - 1}{L_3}\int_{L_1 - L_3}^{L_1 - L_3} \frac{p_b}{p_3}\, d\psi \tag{8}$$

or

$$\left[\frac{T_s}{T_3}\right] = 1 + (\gamma_1 - 1)\left(\frac{V}{u_o}\right)^2 \frac{p_o}{p_1}\left[\left(\frac{T_1}{T_3}\right) - \frac{p_1}{p_3}\right] + \frac{\gamma_1 - 1}{L_3}\int_{L_1 - L_3}^{L_1 - L_3} \frac{p_b}{p_3}\, d\psi \tag{9}$$

or

$$a_s^2 = a_3^2 + (\gamma_1 - 1)\left(\frac{V}{u_o}\right)^2 \frac{p_o}{p_1} a_1^2 \left[1 - \frac{\rho_1}{\rho_3}\right] + \frac{\gamma_1 - 1}{L_3} \int_{L_1 - L_3}^{L_1 - L_3} \frac{p_b}{\rho_3} dy$$

with U_o defined as $\sqrt{2 p_o A_1 (L_1 - L_3)/M}$

The maximum temperature, T_s, is seen to be equal to T_3 plus the kinetic energy of the piston and the work done by the back chamber gas on the piston and front gas. The latter term is in many cases negligible.

The procedure in calculating T_s is illustrated on the flow diagram on the next page; here the last term (the work term) in equation (9) has been assumed negligible.*

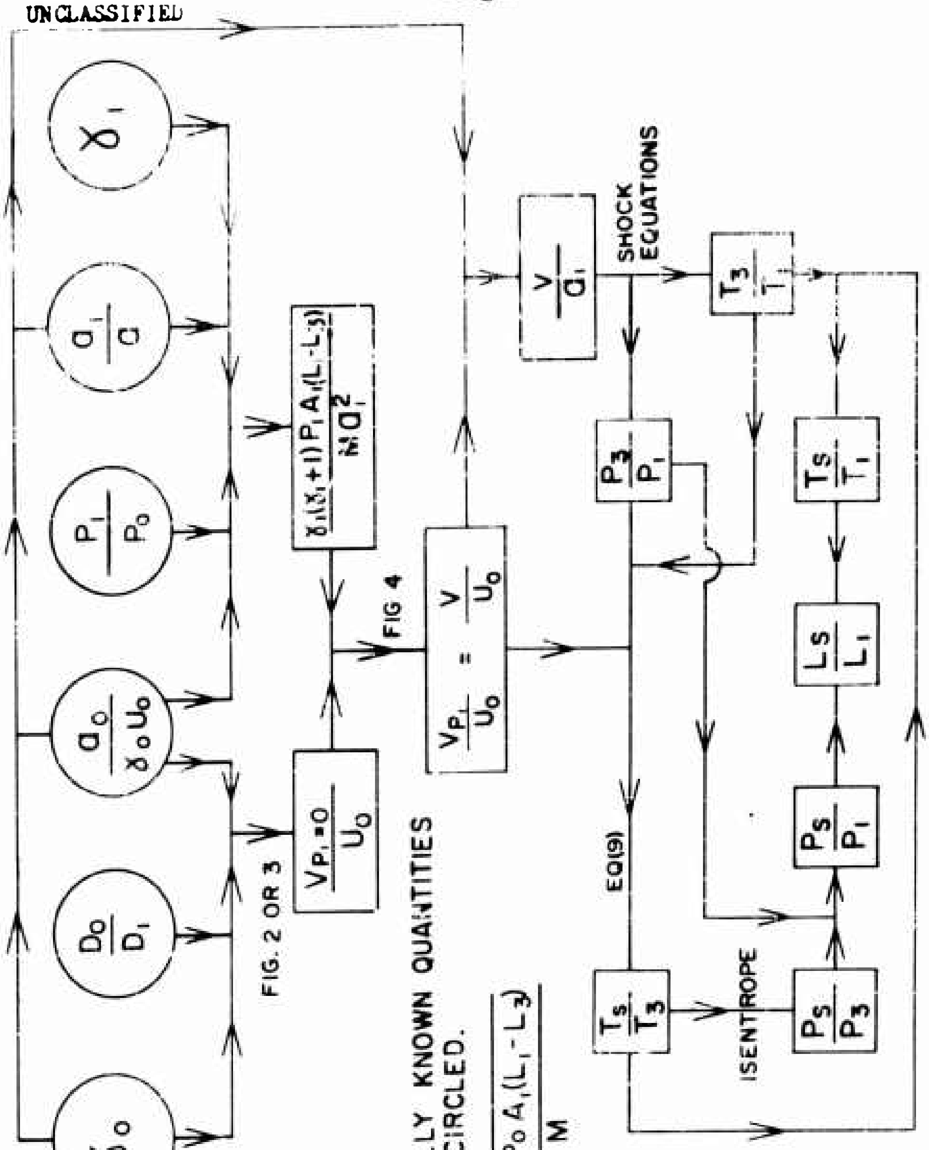
With p_s and T_s (yielding a_s) as the reservoir conditions, the projectile velocity may be calculated using Figures 2, 4, and 5. It must be cautioned that one should determine if the front chamber containing the gas in state S is effectively infinite; if it is not, one should account for the rarefactions by numerical methods or a plot such as Figure 3.

The above method of calculation for two-stage guns has been compared to results obtained by means of an electronic computing machine. Figures 7, 8, and 9 show the computing machine calculated results of the behavior of a 20-mm two-stage gun. This gun is now being used at the U. S. Naval Ordnance Laboratory. The piston used in this gun is termed a "light piston" (being about twice the weight of a nylon sphere). Figure 7 is a distance-time plot showing the trajectories of shocks between the piston and projectile, the piston trajectory, and the projectile trajectory. Figure 8 is a plot of pressure behind the piston (p_b) as a function of time. This result confirms the assumption that the work done by this pressure behind the piston is negligible. Figure 9 is a plot of the projectile velocity versus barrel length. Evidence of the shock impinging on the back of the projectile is seen in this figure. The pressure calculated by the computing machine as a function of time at a position in the front chamber is compared in Figure 10 to the experimentally obtained trace.

*To determine the magnitude of this term, one may use assumption (3) to obtain the pressure p_{SS}. Then it has been found that a good approximation to the average p_b is to use $(p_{SS} + p_{33})/5$.

Seigel

UNCLASSIFIED



INITIALLY KNOWN QUANTITIES ARE CIRCLED.

$$U_0 = \sqrt{\frac{2P_0 A_1 (L_1 - L_3)}{M}}$$

Although the details of the shock reflections in the front gas of a two-stage gun are not obtained (without a good deal of additional labor) by the approximate methods of calculations outlined above, the performance of the projectile is predicted very well. Moreover, the effect of changing any of the gun system parameters is easily calculated. For example, increasing the initial pressure, p_1, in the front chamber while keeping all other parameters the same is found to decrease the temperature, T_s, pressure, p_s, and projectile velocity. In this manner the use of these methods provides an insight not otherwise obtained into the processes occurring, and is a guide to the selection of the gun and gas parameters.

APPENDIX

METHOD OF OBTAINING U_L, THE PISTON VELOCITY, WHEN THE PRESSURE IN THE FRONT BECOMES EQUAL TO THE PRESSURE IN THE BACK OF THE PISTON

The velocity acquired by the piston when the rising front pressure, p_f, equals the dropping back pressure, p_b, is obtained by equating the pressures in terms of velocities. To approximate the behavior of the propellant gas in the back in a chambered gun, it may be assumed that this gas has the same pressure-velocity relation as the driver gas in a shocktube. Then it may be shown from reference (2) that for subsonic flow behind the piston

$$p_b = p_o \left\{ 1 - \frac{u\left[1 - \frac{\gamma_o + 1}{4}\left(1 - A_1/A_o\right)\right]}{2a_o/(\gamma_o - 1)} \right\}^{\frac{2\gamma_o}{\gamma_o - 1}} \tag{a}$$

and for supersonic flow

$$p_b = p_o \left\{ 1 - \frac{u - a_o\left(1 - A_1/A_o\right)/2}{2a_o/(\gamma_o - 1)} \right\}^{\frac{2\gamma_o}{\gamma_o - 1}} \tag{b}$$

From the shock relations the pressure in front of the piston (with the assumption of no gradient between the shock and the piston) is

$$p_f = p_1 \left\{ 1 + \frac{\gamma_1(\gamma_1 + 1)}{4}\left(\frac{u}{a_1}\right)^2 + \gamma_1 \frac{u}{a_1}\sqrt{1 + \left(\frac{\gamma_1 + 1}{4}\,\frac{u}{a_1}\right)^2} \right\} \tag{c}$$

To obtain U_L one needs only to equate the back pressure, p_b, from equation (a) or (b) to the front pressure, p_f, from equation (c), letting in this case the velocity U equal U_L.

REFERENCES

(1) Seigel, A. E., "The Effect of the Optimum Chambrage on the Muzzle Velocity of Guns with a Qualitative Description of the Fundamental Phenomena Occurring During Gun Firing," NavOrd Report 2691 (1952)

(2) Seigel, A. E., "Theoretical Study of the Effect of the Non-ideality of a Dense Shocktube Driver Gas with Special Reference to Non-Uniform Shocktubes," NavOrd Report 5707 (1957)

(3) Seigel, A. E., "The Influence of Chamber Diameter on the Muzzle Velocity of a Gun with an Effectively Infinite Length Chamber," NavOrd Report 3635 (1954)

(4) Heybey, W., "A Solution of Lagrange's Problem of Interior Ballistics by Means of its Characteristic Lines," NOLM 10819 (1950)

(5) Courant, R., and Friedricks, K. O., "Supersonic Flow and Shock Waves," Interscience (1948)

(6) Corner, J., "Theory of Internal Ballistics of Guns," Wiley (1950)

(7) Seigel, A. E., "A Study of the Applicability of the Unsteady One-Dimensional Isentropic Theory to an Experimental Gun," NavOrd Report 2692 (1952)

(8) Seigel, A. E., and Slawsky, Z. I., "A Hypervelocity Gun Using a Shock-Compressed Steam-Heated Propellant," NavOrd Report 4345 (1956)

(9) Evans and Evans, "Shock Compression of a Perfect Gas," Journal of Fluid Mechanics, Vol I, Pt. 4

(10) Smith, F., "The Development of a Hypersonic Launcher," ARDE Report (B) 18/58, Fort Halstead

(11) Curtis, John, NASA TM in publication

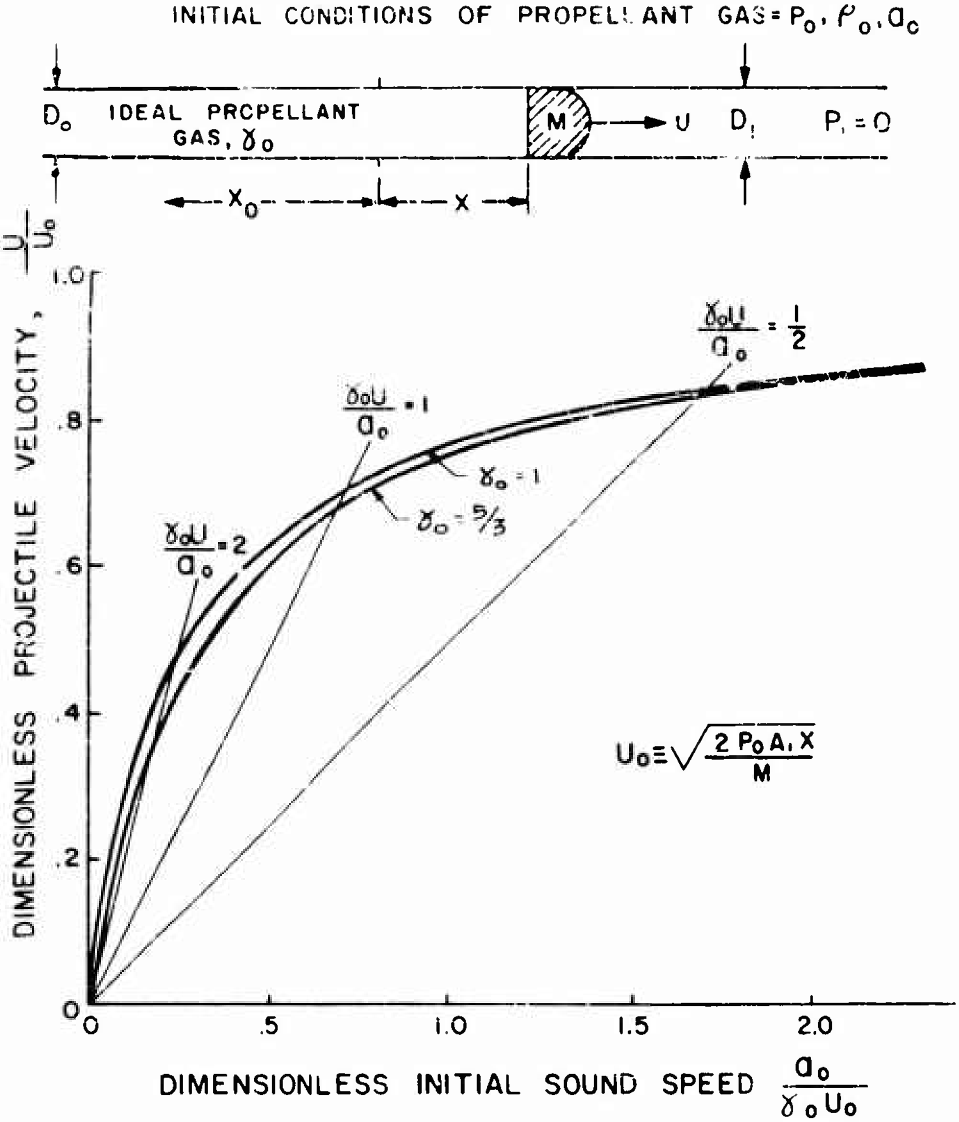


FIG. 1 PROJECTILE VELOCITY - INITIAL SOUND SPEED PLOT FOR ALL γ_0's ($D_0/D_1 = 1_0$, $X_0 = \infty$)

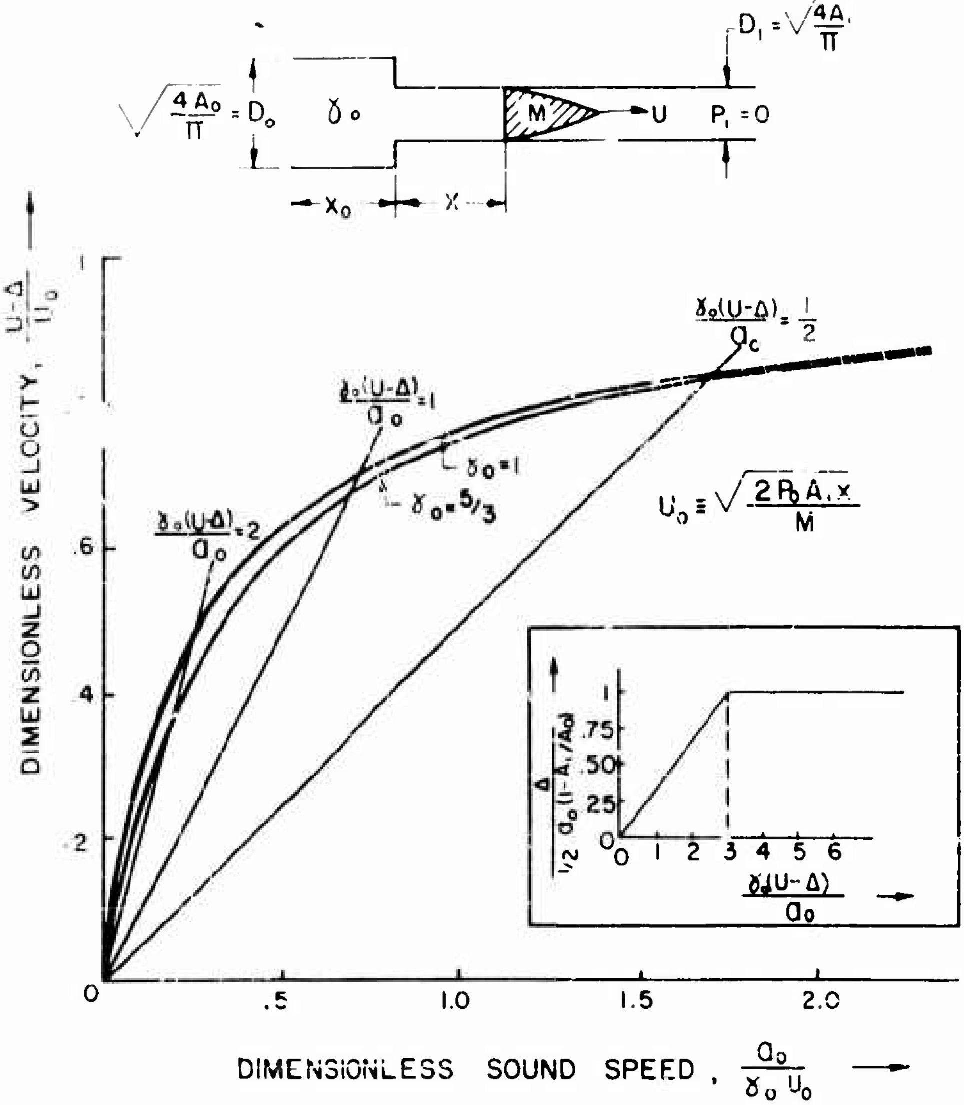


FIG. 2 PERFORMANCE CURVE FOR PRE-BURNED PROPELLANT GUN WITH $D_0/D_1 > 1$, $X_0 = \infty$

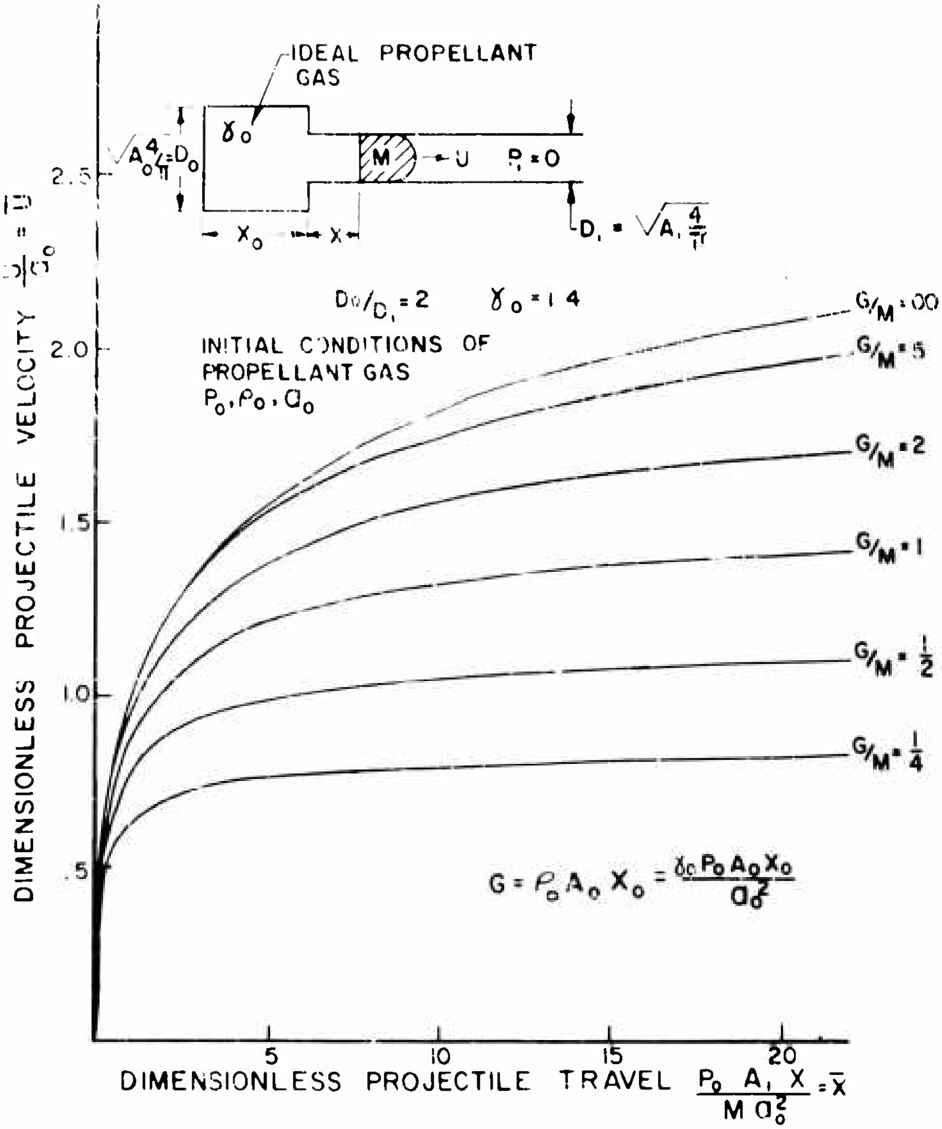


FIG. 3 PROJECTILE VELOCITY TRAVEL PLOT FOR PREBURNED PROPELLANT GUN ($D_0/D_1 = 2$, $\gamma = 1.4$)

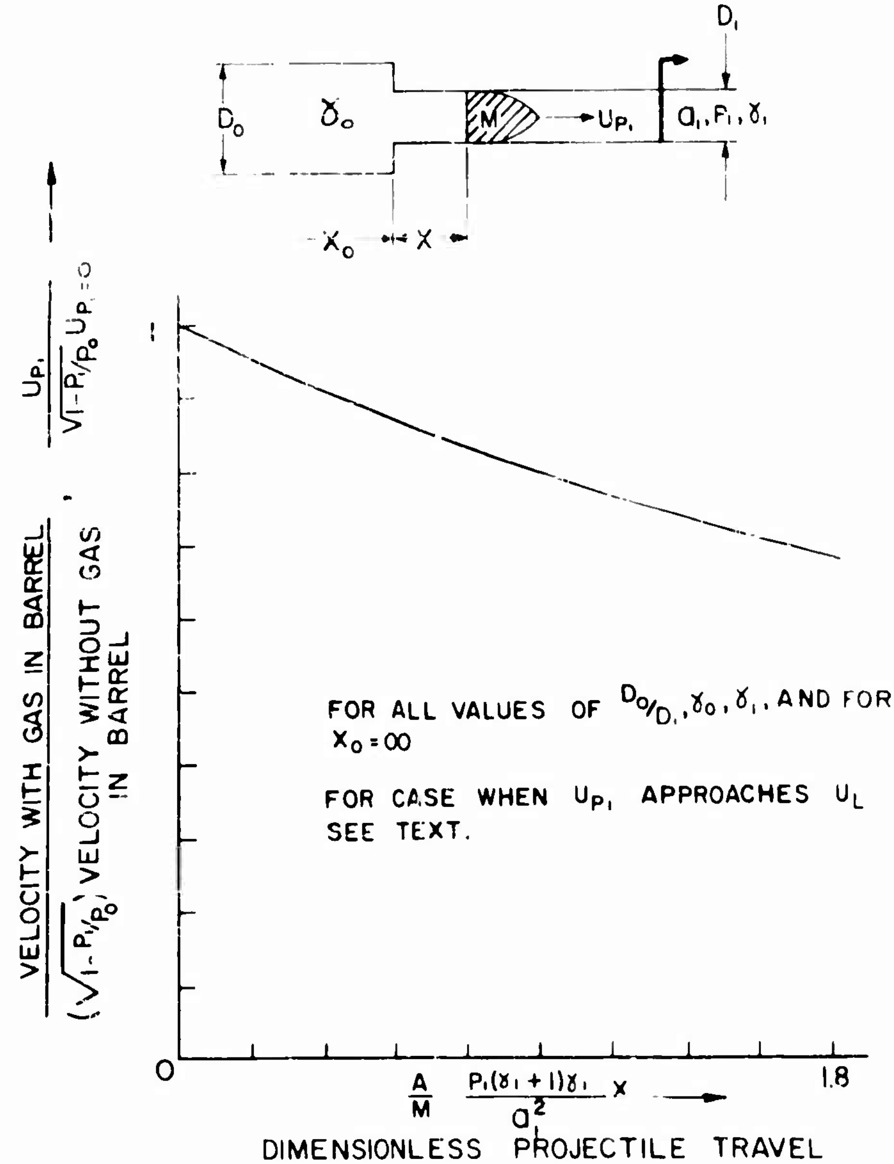


FIG. 4 APPROXIMATE PROJECTILE VELOCITY FOR CASE WHEN GAS IS PRESENT IN BARREL IN FRONT OF PROJECTILE.

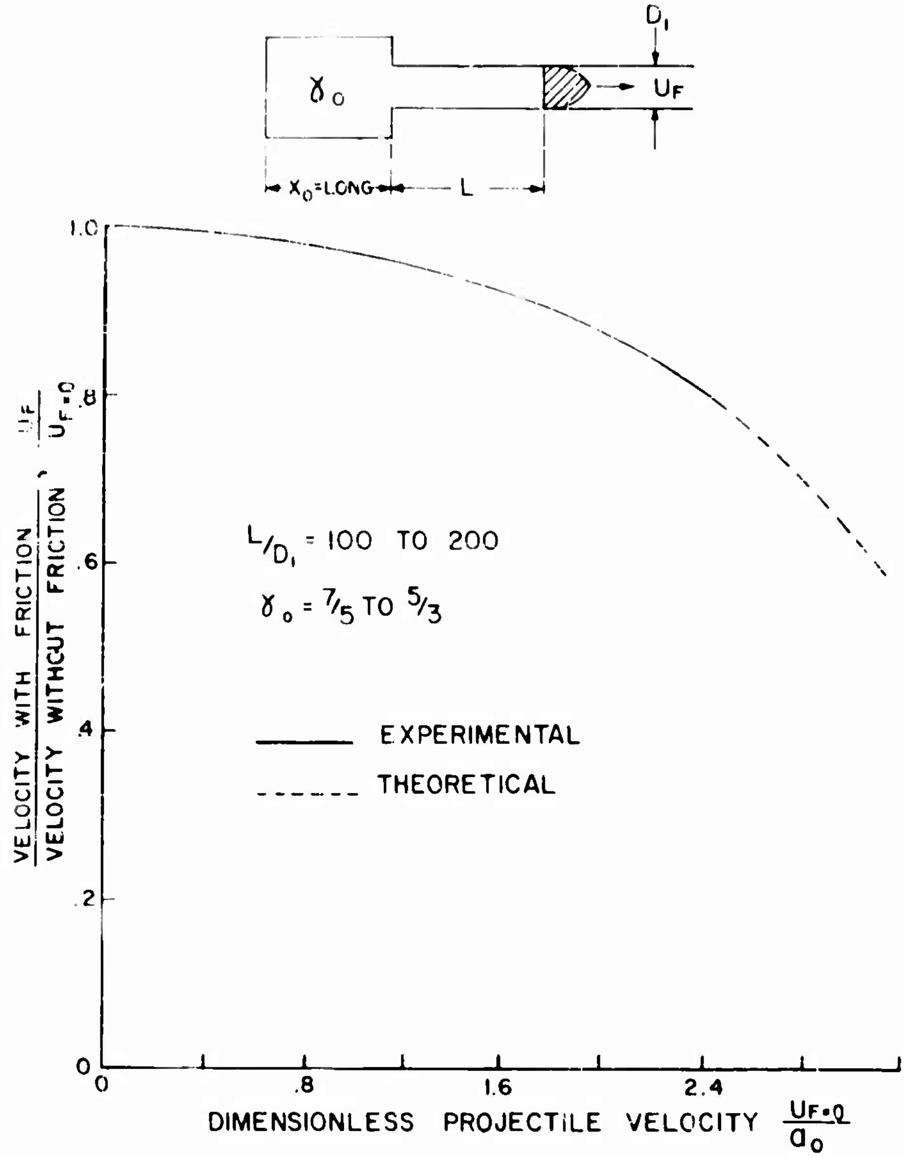


FIG. 5 TENTATIVE PROJECTILE VELOCITY PLOT TO BE USED TO ACCOUNT FOR VISCOUS EFFECTS.

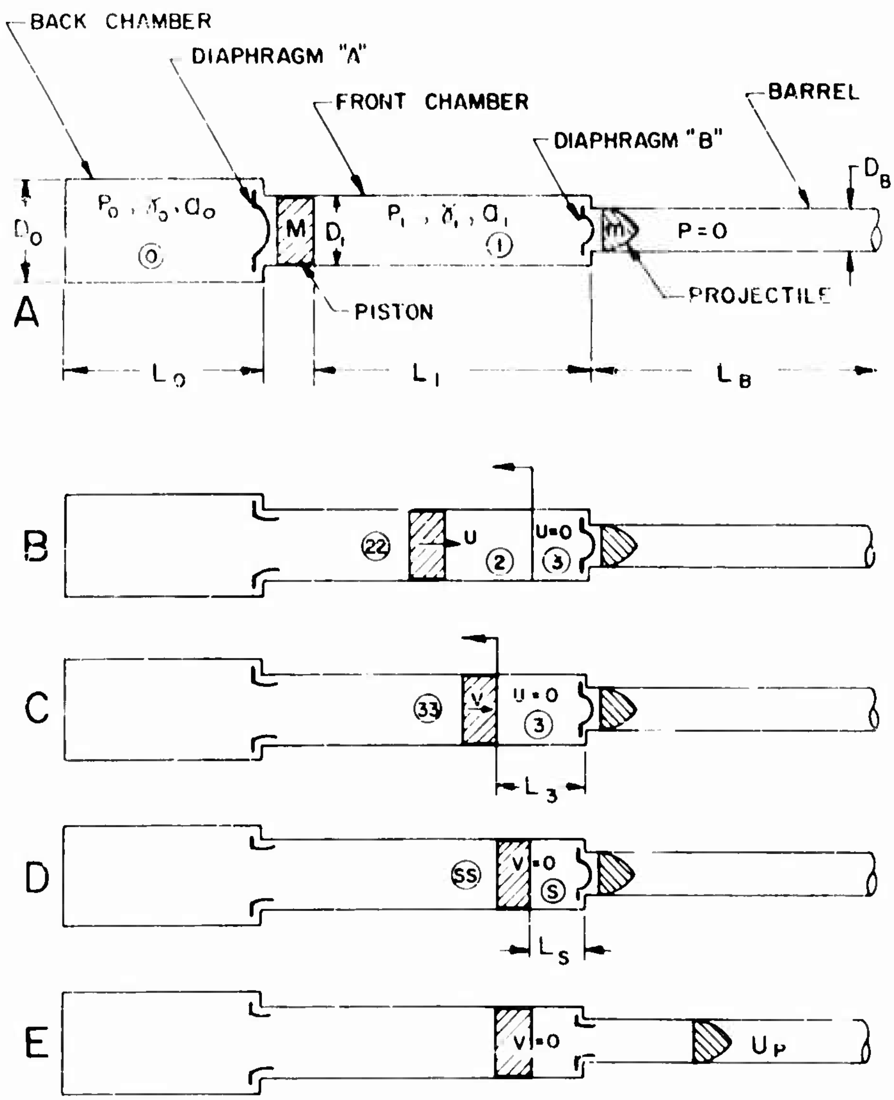


FIG. 6 SEQUENCE OF EVENTS OCCURRING IN TWO STAGE GUN.

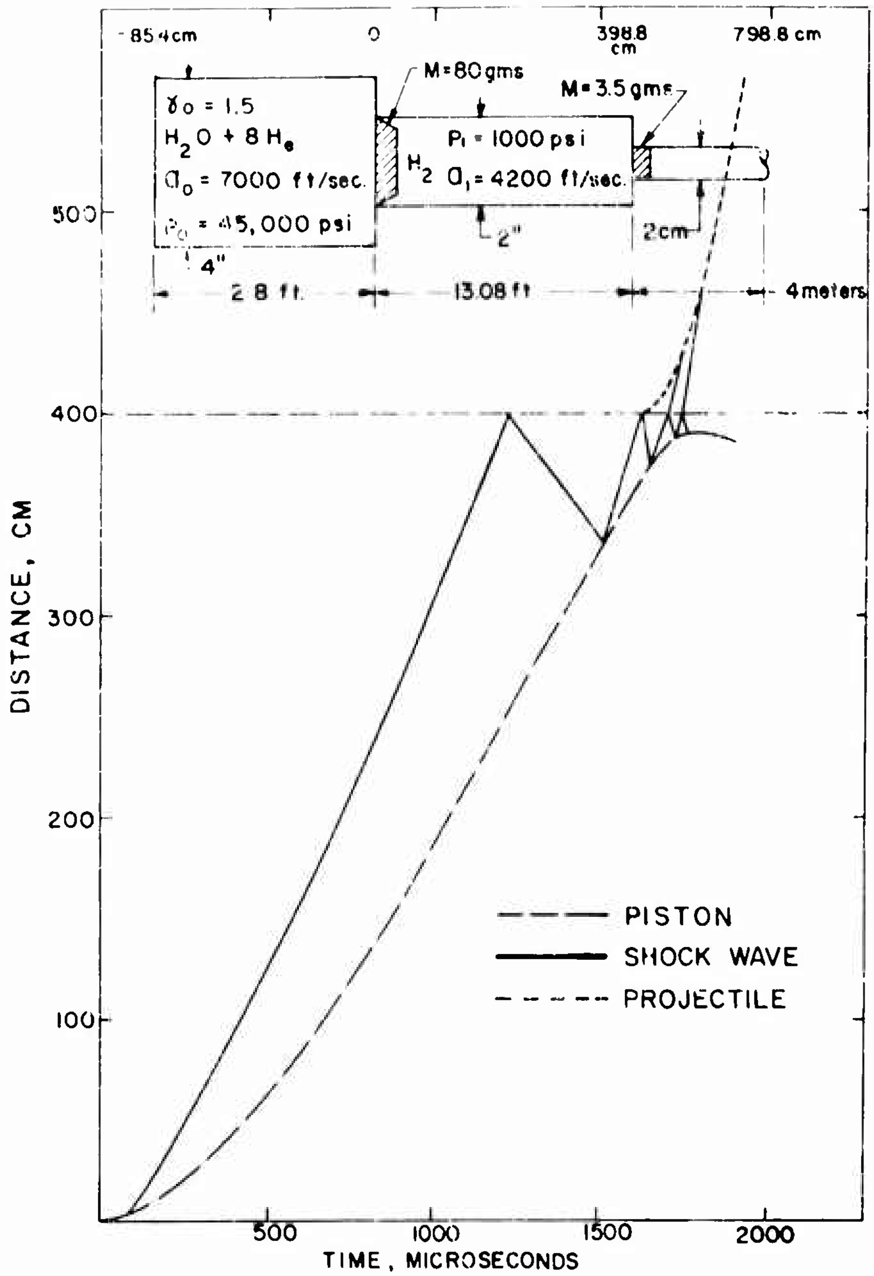


FIG. 7 TWO STAGE GUN TIME - DISTANCE PLOT

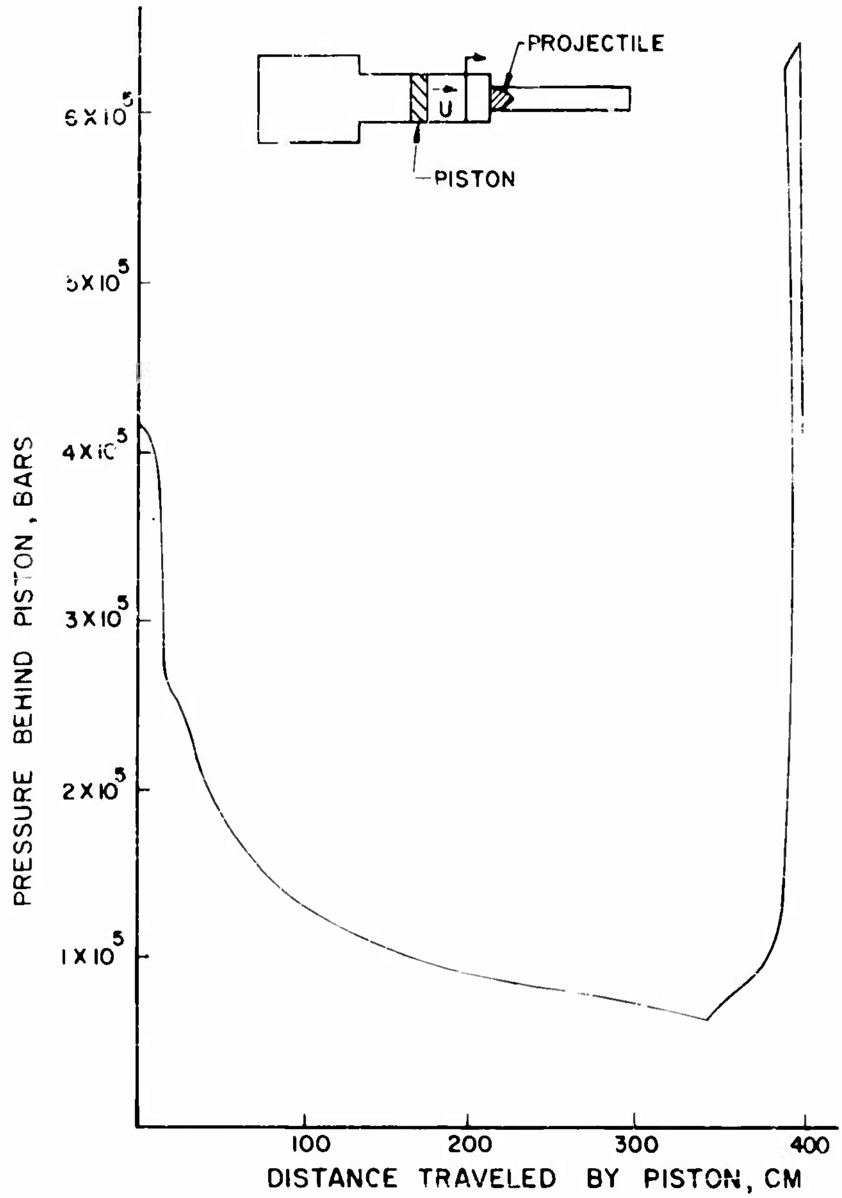


FIG. 8 PRESSURE BEHIND PISTON GIVEN AS A FUNCTION OF POSITION

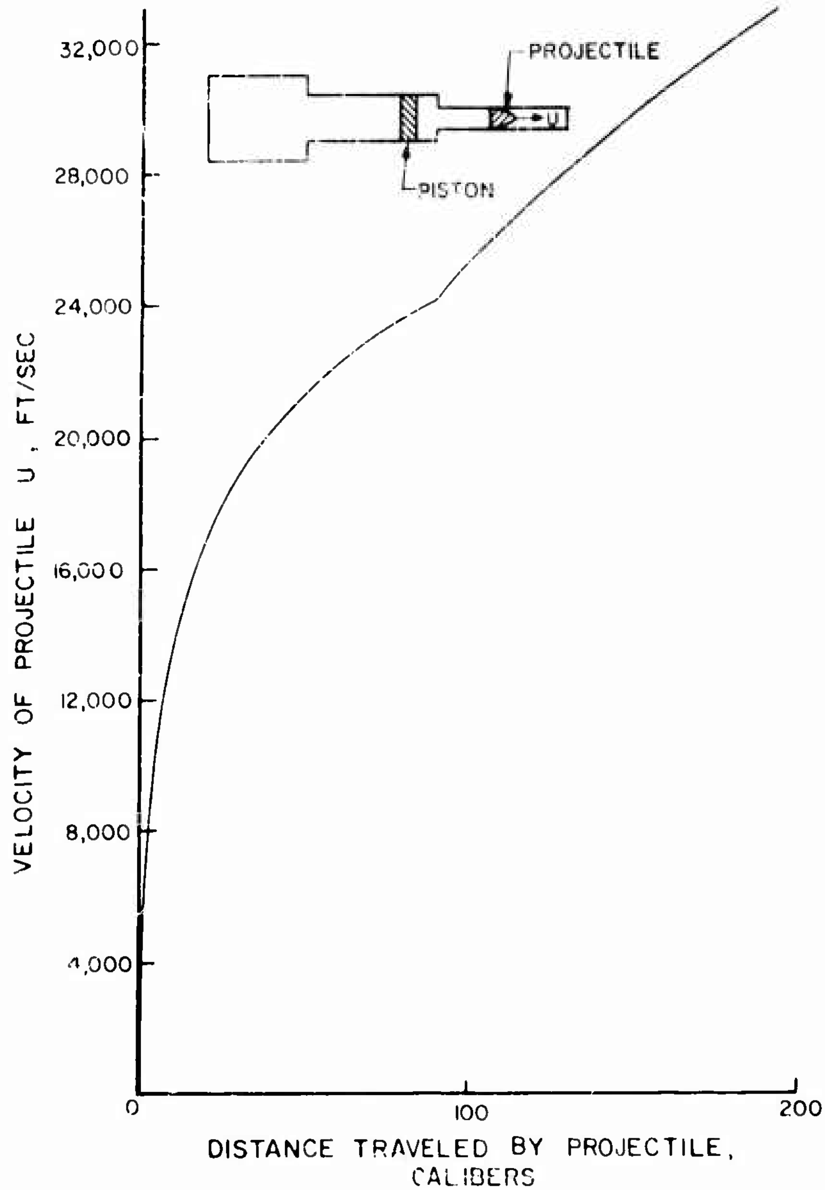


FIG. 9 PROJECTILE VELOCITY IN 2-STAGE LAUNCHER VS TRAVEL DISTANCE IN CALIBERS.

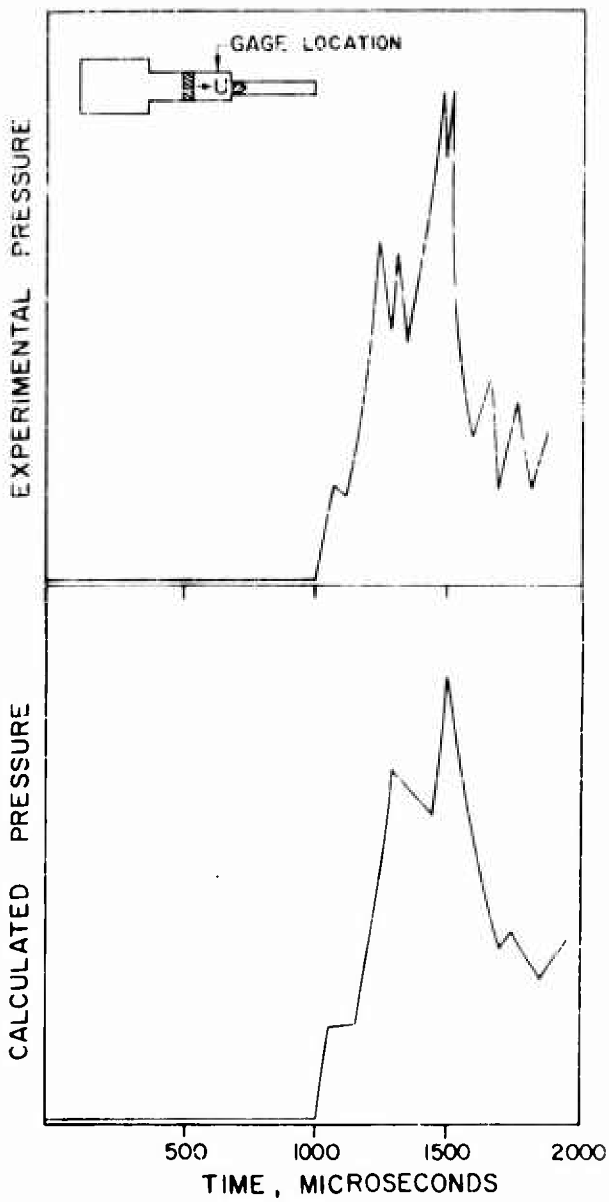


FIG. 10 TYPICAL EXPERIMENTAL PRESSURE TRACE IN FRONT CHAMBER.

BALLISTICS DEPARTMENT
External Distribution List

No. of Copies		No. of Copies	
	Chief Bureau of Naval Weapons Department of the Navy Washington 25, D. C.		Director Naval Research Laboratory Washington 25, D. C.
4	Attn: DIS-3	1	Attn: Code 2027
1	Attn: RMMO	1	Attn: Code 6310
1	Attn: RMGA		
1	Attn: RRMA		NASA Langley Research Center Langley Field, Va.
	Director, Special Projects Department of the Navy Washington 25, D. C.	1	Attn: Librarian
		1	Attn: C. H. McLellan
		1	Attn: J. J. Stack
4	Attn: SP-20	1	Attn: Adolf Busemann
2	Attn: SP-27		
1	Attn: SP-272		NASA Ames Research Center Moffett Field, California
	Office of Naval Research Room 2709 - T-3 Washington 25, D. C.	4	Attn: Librarian
		1	Attn: John Curtis
2	Attn: Head, Mechanics Branch	1	Attn: Harvey Allen
		1	Attn: Thomas Canning
		1	Attn: A. Sieff
5	Commanding Officer Office of Naval Research Branch Office, Box 39 Navy 100 Fleet Post Office New York, N. Y.		Office of the Assistant Secretary of Defense (R and D) Room 3E1041, The Pentagon Washington 25, D. C.
		1	Attn: Tech. Library
	Director David Taylor Model Basin Aerodynamics Laboratory Washington 7, D. C.		Research and Development Board Room 3D1041, The Pentagon Washington 25, D. C.
1	Attn: Library	2	Attn: Library
	Naval Weapons Laboratory Dahlgren, Va.		ASTIA Arlington Hall Station Arlington 12, Va.
1	Attn: Library	10	Attn: TIPDR
	Commander U. S. Naval Ordnance Test Station China Lake, California		Commander, NAMTC Point Mugu, California
1	Attn: Tech. Library	1	Attn: Tech. Library

No. of Copies	
	NASA Lewis Research Center 21000 Brookpart Road Cleveland, Ohio
1	Attn: Librarian
	Director Aberdeen Proving Ground Maryland
1	Attn: Tech. Info Br.
1	Attn: Ballistics Research Lab.
	Director of Intelligence Headquarters, USAF Washington 25, D. C.
1	Attn: AFOIN-3B
	Commander Wright Air Development Division Wright-Patterson AF Base Ohio
2	Attn: WCOSI-3
	Commander, AFBMD Air Research and Development Command P. O. Box 262 Inglewood, California
1	Attn: WDTLAR
1	Attn: WDTVR
	Commander, AEDC Tullahoma, Tenn.
1	Attn: Tech. Library
1	Attn: J. Lukasiewicz
1	Attn: W. B. Stephenson
	Commanding Officer, DOFL Washington 25, D. C.
1	Attn: Library Rm. 211, Bldg. 92

No. of Copies	
	Office, Chief of Ordnance Department of the Army Washington 25, D. C.
1	Attn: ORDTU
	NASA George C. Marshall Space Flight Center Huntsville, Alabama
1	Attn: Dr. Ernst Geissler
1	Attn: Tech. Library
	NASA 1520 H Street, N. W.
1	Washington, D. C.
1	Attn: Dr. H. H. Kurzweg
	Commanding General Army Rocket and Guided Missile Agency Redstone Arsenal, Alabama
1	Attn: John Morrow
	NASA High Speed Flight Station Edwards Field, California
1	Attn: W. C. Williams
	Office of Technical Services Department of Commerce
10	Washington 25, D. C.
	Defense Systems Division General Motors Santa Barbara, California
2	Attn: Librarian
1	Attn: Dr. A. C. Charters
	AVCO Research Laboratory Everett, Mass.
1	Attn: Jerome Eckerman
1	Attn: W. McKay
1	Attn: Dr. A. Kantrowitz
1	Attn: Mr. S. Feldman
1	Attn: Mr. M. Petschek
1	Attn: Tech. Library

No. of Copies		No. of Copies	
	Los Alamos Scientific Lab. Los Alamos, New Mexico		General Electric Research Laboratory Schenectady, New York
1	Attn: Dr. R. E. Duff	1	Attn: Dr. R. A. Alpher
1	Attn: Librarian	1	Attn: Dr. D. R. White
		1	Attn: Dr. H. Nagamatsu
	National Bureau of Commerce Heat and Power Division Building 108 Washington, D. C.		University of Maryland College Park, Maryland
1	Attn: Librarian	1	Attn: Prof. W. Sherwood
		1	Attn: Prof. J. Jackson
	Massachusetts Institute of Technology Cambridge 39, Mass.	5	Attn: Dr. J. M. Burgers
		1	Attn: Dr. E. Mason
		1	Attn: Dr. J. Vanderslice
1	Attn: Prof. A. Shapiro	1	Attn: Dr. H. Schamp
1	Attn: Prof. J. Keenan	1	Attn: Dr. Pai
1	Attn: Prof. A. Stever	1	Attn: Prof. Shreve
	The Johns Hopkins University Charles and 34th Streets Baltimore 18, Maryland		Convair A Division of General Dynamics Corporation San Diego 12, California
1	Attn: Dr. F. H. Clauser	1	Attn: Dr. J. A. L. Thomson
		1	Attn: Tech. Library
	Director Inst. for Fluid Dynamics and Applied Mathematics University of Maryland		Holloman Air Force Base Alamogordo, New Mexico
		1	Attn: Dr. G. Eber
2	College Park, Maryland		
	Cornell University Graduate School for Aero. Engineering Ithaca, New York		Engineering Library Republic Aviation Corp.
		1	Farmingdale, New York
			Brown University Providence, Rhode Island
1	Attn: Prof. W. R. Sears		
1	Attn: Prof. E. Resler	1	Attn: Librarian
1	Attn: Prof. S. F. Shen		
	Grumman Aircraft and Engineering Company New York, N. Y.		Princeton University James Forrestal Research Center Gas Dynamics Laboratory Princeton, New Jersey
1	Attn: Dr. S. Ciolkowski	1	Attn: Prof. S. Bogdonoff
	Stanford Research Institute Palo Alto, California		E. H. Plesset Associates 6899 Wilshire Boulevard
1	Attn: Dr. T. C. Poulter	1	Los Angeles 40, Calif.

No. of Copies

Giannini Research Company
18400 South Main Street
Santa Ana, California
1 Attn: Dr. V. H. Blackman

Arthur D. Little, Inc.
30 Memorial Drive
Cambridge 42, Mass.
1 Attn. Library

The Catholic University of America
Washington, D. C.
1 Attn: Library

Nuclear Development Associates
White Plains, New York
1 Attn: Dr. M. Silberstein

AF Office of Scientific Research
Washington, D. C.
1 Attn: Librarian
1 Attn: Dr. M. Slawsky

Lehigh University
Physics Department
Bethlehem, Pa.
1 Attn: Dr. R. Emrich

University of Toronto
Institute of Aerophysics
Toronto, Canada
1 Attn: Dr. G. Patterson
1 Attn: Dr. I. I. Glass

Yale University
Physics Department
New Haven 11, Conn.
1 Attn: Dr. H. Margenau
1 Attn: Dr. D. E. Kelly

No. of Copies

Yale University
Mechanical Engineering Dept.
New Haven 11, Conn.
1 Attn: Dr. P. Wegener
1 Attn: Dr. N. Hall

Lockheed Aircraft Corp.
Palo Alto, California
1 Attn: Library

Princeton University
Aeronautics Department
Princeton, New Jersey
1 Attn: Librarian

Princeton University
Palmer Physical Laboratory
Princeton, New Jersey
1 Attn: Dr. W. Bleakney

University of Wisconsin
Department of Chemistry
Madison, Wisconsin
1 Attn: Dr. J. Hirschfelder

University of Michigan
Ann Arbor, Michigan
1 Attn: Dr. O. Laporte
1 Attn: Prof. W. C. Nelson
1 Attn: Dr. Arnold Kuethe

National Science Foundation
Washington 25, D. C.
1 Attn: Dr. R. Seeger
1 Attn: Dr. J. H. McMillen

Pennsylvania State College
Department of Aeronautical Engineering
State College, Pa.
1 Attn: Prof. M. Lessen

No. of Copies		No. of Copies	
	Superintendent U. S. Naval Postgraduate School Monterey, California		Ohio State University Research Foundation Columbus 10, Ohio
1	Attn: Technical Reports Section, Library	1	Attn: Security Officer
	Director Air University Library		California Institute of Technology Pasadena 4, California
1	Maxwell AF Base, Alabama	1	Attn: Aeronautics Dept.
		1	Attn: Dr. S. S. Penner
		1	Attn: Prof. L. Lees
	Aro, Incorporated Tullahoma, Tenn.		
1	Attn: Gas Dynamics Facility		Jet Propulsion Laboratory California Institute of Technology Pasadena 4, California
		1	Attn: Library
	University of California Berkeley 4, California		
1	Attn: G. J. Maslach		University of Minnesota Minneapolis, Minn.
1	Attn: Dr. S. A. Schaaf	1	Attn: Mech. Engr. Dept.
	Defense Research Laboratory University of Texas P. O. Box 8029 Austin 12, Texas		BAR Aerojet-General Corporation 6325 Irwindale Avenue
1	Attn: H. D. Krick	1	Azusa, California
	Applied Mathematics and Statistics Laboratory Stanford University		Rand Corporation 1700 Main Street Santa Monica, California
1	Stanford, California	1	Attn: Library
	Supervisor Technical Documents Services Willow Run Laboratories University of Michigan Willow Run Airport Ypsilanti, Michigan		Convair A Division of General Dynamics
		1	Daingerfield, Texas
			United Aircraft Corporation 400 Main Street East Hartford 8, Conn.
	APL/JHU 8621 Georgia Avenue Silver Spring, Maryland	1	Attn: Chief Librarian
2	Attn: Tech. Rpts. Group		Guggenheim Aeronautical Lab. California Institute of Technology Pasadena 4, California
		1	Attn: Aeronautics Lab.

No. of Copies		No. of Copies	
	Cornell Aeronautical Laboratory P. O. Box 235 Buffalo 21, New York		National Bureau of Standards Washington 25, D. C.
1	Attn: Librarian	1	Attn: Mr. R. Thompson
1	Attn: Mr. A. Hertzberg	1	Attn: Fluid Mechanics Section
1	Attn: Charles E. Witliff	1	Attn: Applied Math. Div.
1	Attn: H. S. Glick		
1	Attn: W. E. Smith		Douglas Aircraft Company, Inc. Santa Monica Division 3000 Ocean Park Blvd. Santa Monica, California
1	Attn: A. Flax	1	Attn: Mr. Thomas Finch
	Armour Research Foundation 10 West 35th Street Chicago 16, Illinois	1	Attn: Mr. J. Hains
1	Attn. V. F. Volpe	1	Attn: Mr. N. Augustine
1	Attn: F. J. Zimmerman		
2	Attn: Librarian		General Electric Company Missile and Ordnance Systems Department 3198 Chestnut Street Philadelphia 4, Pa.
	Hughes Aircraft Corporation Florence Avenue at Teal St. Culver City, California		
1	Attn: Research and Development Tech. Library	1	Attn: Larry Chasen Manager, Library
	McDonnell Aircraft Corp. P. O. Box 516		Lockheed Aircraft Corp. Missiles and Space Division Summyvale, California
1	St. Louis, Missouri	1	Attn: John Hawes
		1	Attn: Librarian Via: BUWEPS REP P. O. Box 504 Sunnyvale, California
	Eastman Kodak Company Apparatus and Optical Div. 400 Plymouth Avenue North Rochester 4, New York		
2	Attn: Librarian		Ramo-Wooldridge Corporation Inglewood, California
	University of Southern California 3518 University Lane Los Angeles, California	1	Attn: Librarian
1	Attn: Director Engr. Center		The Martin Company Baltimore 3, Maryland
		1	Attn: Library
		1	Attn: Chief Aerodynamicist
	Case Institute of Technology Cleveland 6, Ohio		
1	Attn: G. Kuerti		

No. of
Copies

Denver Research Institute
University of Denver
Denver, Colorado
1 Attn: A. M. Krill
1 Attn: S. A. Johnson
1 Attn: M. W. Burnham
2 Attn: Librarian

Purdue University
Lafayette, Indiana
1 Attn: Library

Colorado School of Mines
Golden, Colorado
1 Attn: John S. Rinehart
Director, Mining
Research Lab.
Mining Engr. Dept.
1 Attn: Library

Watertown Arsenal
Watertown, Massachusetts
1 Attn: Library

Utah Research and
Development Company, Inc.
Salt Lake City, Utah
1 Attn: W. S. Brown
1 Attn: W. A. Boyd
1 Attn: E. T. Canon
1 Attn: W. S. Partridge

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-29)
METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel.
23 June 1961. 28p. charts, diagrs.
UNCLASSIFIED

The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.

1. Projectiles - Performance
2. Projectiles - Propellants
3. Gases, Propellant
4. Guns, Gas
I. Title
II. Seigel, Arnold E.

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-29)
METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel.
23 June 1961. 28p. charts, diagrs.
UNCLASSIFIED

The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.

1. Projectiles - Performance
2. Projectiles - Propellants
3. Gases, Propellant
4. Guns, Gas
I. Title
II. Seigel, Arnold E.

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-29)
METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel.
23 June 1961. 28p. charts, diagrs.
UNCLASSIFIED

The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.

1. Projectiles - Performance
2. Projectiles - Propellants
3. Gases, Propellant
4. Guns, Gas
I. Title
II. Seigel, Arnold E.

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-29)
METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel.
23 June 1961. 28p. charts, diagrs.
UNCLASSIFIED

The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.

1. Projectiles - Performance
2. Projectiles - Propellants
3. Gases, Propellant
4. Guns, Gas
I. Title
II. Seigel, Arnold E.

Naval Ordnance Laboratory, White Oak, Md. (NOL technical report 61-29) METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel. 23 June 1961. 28p. charts, diagrs. UNCLASSIFIED The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.	1. Projectiles - Performance 2. Projectiles - Propellants 3. Gases, Propellant 4. Guns, Gas I. Title II. Seigel, Arnold E.

Naval Ordnance Laboratory, White Oak, Md. (NOL technical report 61-29) METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel. 23 June 1961. 28p. charts, diagrs. UNCLASSIFIED The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.	1. Projectiles - Performance 2. Projectiles - Propellants 3. Gases, Propellant 4. Guns, Gas I. Title II. Seigel, Arnold E.
Naval Ordnance Laboratory, White Oak, Md. (NOL technical report 61-29) METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel. 23 June 1961. 28p. charts, diagrs. UNCLASSIFIED The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.	1. Projectiles - Performance 2. Projectiles - Propellants 3. Gases, Propellant 4. Guns, Gas I. Title II. Seigel, Arnold E.
Naval Ordnance Laboratory, White Oak, Md. (NOL technical report 61-29) METHOD OF CALCULATING PRE-BURNED PROPELLANT GUN PERFORMANCE WITH SPECIAL APPLICATION TO TWO-STAGE GUNS, by A.E. Seigel. 23 June 1961. 28p. charts, diagrs. UNCLASSIFIED The method of calculating the behavior of a projectile propelled by a pre-burned propellant in a chambered gun is reviewed. The influence of gas in front of the projectile in the barrel is discussed as is the procedure to take account of gas frictional and heat-transfer effects. The method of calculation by hand of the performance of two-stage guns is then outlined. Some results obtained from an electronic computing machine are compared to experimental results.	1. Projectiles - Performance 2. Projectiles - Propellants 3. Gases, Propellant 4. Guns, Gas I. Title II. Seigel, Arnold E.